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ABSTRACT

The extent to which collaborative research, conducted in partnerships between universities and the business sector, influences the nature of scientific production and the level of international scientific collaboration is examined. The more specific question of whether collaborative research reduces the number of scientific publications in general and those arising from international collaboration is also explored. The data used were compiled from the Canadian bibliometric database produced by the Observatoire des sciences et des technologies with funding from Statistics Canada. Publications were coded and analyzed for the years 1980, 1985, 1990, and 1995. Total scientific production of researchers increased by 80% between 1980 and 1995, and the share of scientific production that grew from intersectoral collaborations increased by 155%, although this rate of increase had begun to subside from 50% in the early 1980s to 27% in the early 1990s. Almost one-third of the scientific production of universities is produced in collaboration with foreign partners. Collaborative research does not appear to have a negative impact on the production of researchers. Intersectoral collaboration does tend to produce research that is more applied than that which is undertaken solely with university colleagues, and intersectoral partnerships do tend to affect slightly the level of international collaboration of university researchers. However, the average impact of intersectoral collaborative research is not significantly different from that of university research, suggesting that collaborative research is not incompatible with quality. (SLD)

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Introduction

Over the past 15 years, we have witnessed, according to some analysts, a trend toward greater heterogeneity in scientific research and growing collaboration of university researchers with partners outside the university sector. This is one of the five characteristics that, according to Gibbons et al. (1994), defines today's new modes of knowledge production. Primed by recent science policies, governments urge researchers to increase the relevance of their work. To this end, governments actively promote through diverse policy mechanisms greater collaboration and exchange among universities, businesses and governments.

The rapid growth of collaboration between universities and the business sector has raised many questions among academics concerned that the more applied nature of the knowledge produced by such partnerships could be at

Highlights

- Total scientific production of university researchers increased by 80% over the fifteen-year period between 1980 and 1995. By comparison, scientific production that grew out of inter-sectoral collaborations increased by 155%, its share rising from 15% to 21%. The rate of growth of inter-sectoral collaboration is subsiding, however, from 50% in the early 1980s to 27% in the early half of the 1990s.
- In the health fields, university researchers tend to pair up with hospital researchers, while the federal laboratories are the main partners of researchers in fields such as biology, space and earth sciences, physics and chemistry. Engineering researchers collaborate principally with private sector firms.
- Almost one-third (30.4%) of scientific production of universities is produced in collaboration with foreign partners, up from 16% in 1980. This frequency of international collaboration is twice the level found at the world level.
- Since the 1980s, Canadian university researchers reduced their reliance on American colleagues as collaborators. However, this diversification did not result in more frequent collaboration with European researchers, with the exception of Germany. Rather, Canadian researchers turned to Asia, notably Japan, and to smaller industrialized countries such as the Netherlands in their search for partners.
- Collaborative research does not appear to have a negative impact on the production of researchers. The most productive are also those who partner with researchers in other sectors. Inter-sectoral collaboration does tend to be more applied than that which is undertaken solely with university colleagues. Moreover, inter-sectoral partnerships do tend to affect slightly the level of international collaboration of university researchers.
- Contrary to widespread expectations, the average impact of inter-sectoral collaborative research is not significantly different from that of university research. Hence, collaborative research is not incompatible with quality.

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the expense of more fundamental research, the traditional objective of university research.

Few studies, however, have sought to measure the effect of collaboration on university research. The few studies available paint a more nuanced picture: researchers active in collaboration do not necessarily participate in such activity at the expense of more academic pursuits (Blumenthal, 1996; Godin, 1998). The object of this report is to assess the extent to which collaborative research influences the nature of scientific production and the level of international scientific collaboration. More specifically, we seek to answer the following questions: does collaborative research, because of the demands it imposes on the limited time and resources of researchers, lead to a reduction in the number both of scientific publications in general and of publications arising from international collaboration? Are university publications written with industries or government laboratories more applied than those written only with university researchers? Is there a difference in the average impact factor of publications written in collaboration with non-university researchers?

Before answering these questions, we will briefly present the database and the methodology used in this report.

Database and Methodology

The data used in this study were compiled from the Canadian bibliometric database produced by the Observatoire des sciences et des technologies (OST) with funding from Statistics Canada (Godin, Gingras, Davignon, 1998). The database consitst of publications by Canadian researchers indexed in the *Science Citation Index* (SCI). The period covered by the database runs from 1980 to 1997. For our purposes, the analysis was restricted to the years 1980, 1985, 1990 and 1995. In each year, Canadian publications were analyzed according to whether they were produced in domestic or international collaboration.

Each publication was coded according to the discipline of the journal in which it appeared using CHI classification. Scientific production was measured in 108 specialties, grouped into eight disciplinary sets: biomedical research, clinical medicine, biology, chemistry, earth and space sciences, engineering, physics, and mathematics.

Each address included in a publication was attributed to one of the following five sectors: universities, business firms, government laboratories (provincial and federal), hospitals, and colleges. Publications written by at least one university author together with at least one author from one of the other sectors are referred to as inter-sectoral publications.

Following standard bibliometric techniques, publications are counted on the basis of addresses and not authors (the SCI does not allow the assignment of a specific address to a particular author). Thus, a publication in which there are two university researchers from the same institution, one industrial researcher, and two government researchers from two different federal institutions is treated as follows: the university institution is assigned one publication, the industrial institution is assigned one as well, and the two federal institutions are assigned one publication each.

Results

University production[1]

Publications from the university sector, that is, publications that include at least one university address, represented 82.8% of all Canadian publications in 1996 (Table 1). This share represented 75.0% in 1980. Far

Table 1: University Publications

Year	Number	% of total output
1980	11,838	75.0%
1985	15,218	76.7%
1990	18,153	79.7%
1995	21,008	81.9%
1996	21,336	82.8%

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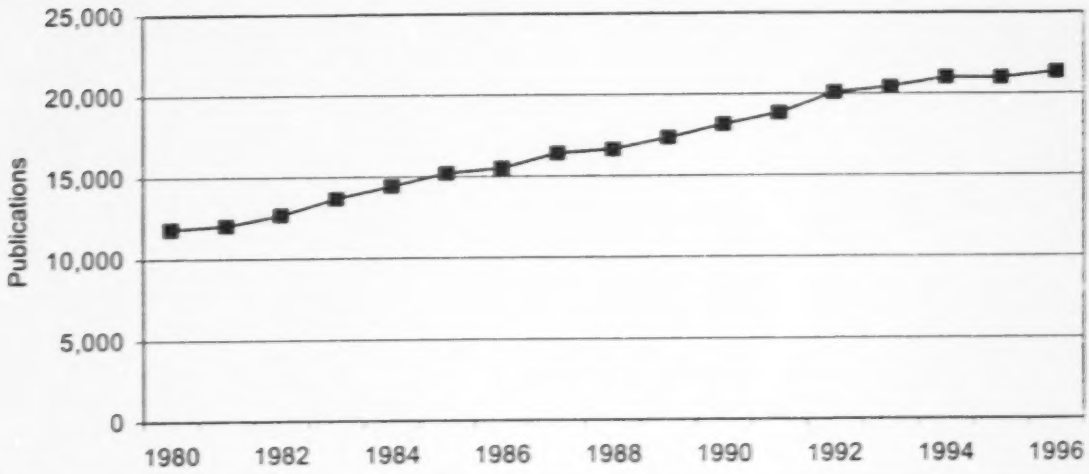
Figure 1: Scientific Production in Canadian Universities



from having decreased, university production has thus never ceased to grow in absolute and relative terms, going from 11,838 publications in 1980 to 21,336 publications in 1996 (Figure 1).

The other sectors are present in the following proportions[2]: hospitals (12.9%), federal laboratories (12.4%), business firms (3.4%), and provincial governments (2.5%).

During the period under consideration, university publications grew by 80.2%. There were, however, some fluctuations in this growth rate over time. It dropped from 21.9% in 1980-1984, to 15.3% in 1984-1988, climbed to 20.6% in 1988-1992, and dropped again to 6.1% between 1992-1996.

Over the same period, the growth in university scientific production is surpassed only by two other sectors: provincial governments, which increased their scientific output by 131.2%, and business firms which grew by 106.6%. Lagging slightly behind universities, hospitals and federal laboratories grew by 75.1% and 30.3%, respectively.

Inter-sectoral collaboration

In 1995, 21% of university publications were the result of collaboration with other sectors (Table 2). In 1980, they represented 14.6%[3]. During the period under study, the proportion of inter-sectoral collaboration grew by 155.2%, from 1,732 to 4,420 publications. But, like the trend of university publications, the growth of collaborative publications fluctuated and, in this case, dwindled over the fifteen-year period. The rate of growth went from 50% between 1980-1985, to 34.3% in 1986-1990, and to 26.6% in 1991-1995.

Inter-sectoral collaboration is unequally distributed among the disciplines (Figure 2). The greatest growth in inter-sectoral

Table 2: University Publications Written in Collaboration With Other Sectors

Year	Number	%
1980	1,732	14.6%
1985	2,598	17.1%
1990	3,490	19.2%
1995	4,420	21.0%

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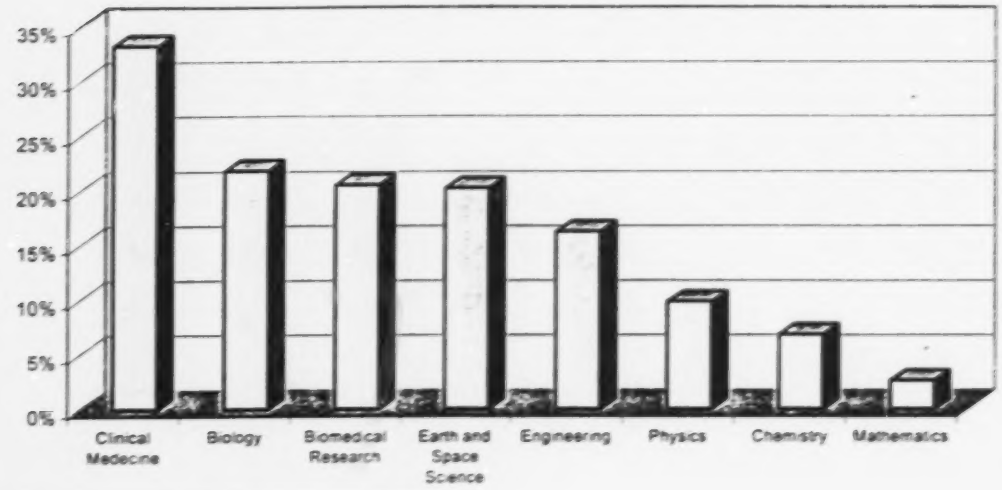
Figure 2: Intersectoral Collaboration by Discipline (1995)



collaboration between 1980 and 1995 is in earth and space sciences (302.4%) and physics (301.8%), followed by biomedical research (281.4%), engineering (218.8%), chemistry (142.9%), biology (141.0%), clinical medicine (103.0%), and mathematics (75.0%).

Clinical medicine is the most active, with 33.2% of its publications produced collaboratively in 1995. This, of course, is due to the strong links between universities and affiliated hospitals. This strong interaction between hospitals and university also explains the fact that nearly half (46.4%) of all inter-sectoral collaboration in 1995 originates from the field of clinical medicine. It is followed by biology (21.8%), biomedical research (20.5%), earth and space sciences (20.2%), engineering (16.2%), physics (9.8%), chemistry (6.8%), and mathematics (2.6%). Clinical medicine and biomedical researchers tend to pair up mainly with hospitals; researcher in biology, earth and space sciences, physics and chemistry with federal laboratories; and engineering with business firms.

Not surprisingly, the principal partner of university researchers was, in 1995, the hospital sector (Figure 3). The latter represents 45.2% of the inter-sectoral collaboration of universities. Hospitals are followed by federal laboratories (23.3%), business firms (10.6%), provincial governments (9.2%), and various other partners (9.0%).

International collaborations

In 1995, 30.4% of university publications were produced with foreign partners (Table 3). In 1980, the level of international collaboration was only half as high, at 16.0%. This percentage is twice the one found at the world level. In fact, small countries are known to collaborate more than bigger ones (Gingras, Godin, and Foisy, 1999).

As compared to inter-sectoral papers, these publications have seen a higher rate of growth. Over the period 1980-1995, publications written through international collaboration grew by 237.2%. It is also this type of publication that had the most stable growth rate over the fifteen-year period, going from 52.7% (1980-1985), to 53.7% (1986-1990), and to 43.7% (1991-1995).

The relationship between Canadian researchers and their collaborators in foreign countries has changed over the course of the period studied. The United States represented 48.7% of Canadian international collaboration in 1980, compared to 38.0% in 1995. The space left by the U.S. has not been filled, however, by other large European countries. Collaboration with the United Kingdom dropped from 11.0% to 7.4% while collaboration with France stayed at 7.2%. Only Germany grew from 3.7% to 5.5%. Asian countries, notably Japan (which grew from

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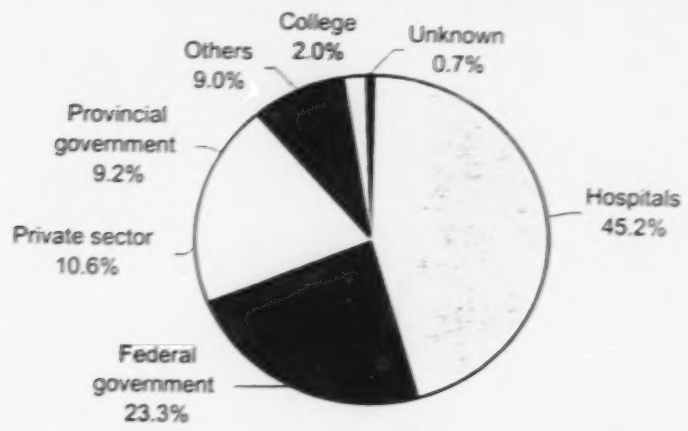
Figure 3: University Collaboration by Sector (1995)



2.5% to 4.8%), and small countries, like the Netherlands, have taken up the room left by the decline of U.S. collaboration with Canada.

To sum up, university production has increased over the last fifteen years. Collaboration has also increased, particularly international collaboration which has increased more than inter-sectoral collaboration.

Highly productive researchers

In order to check if collaborative research has a negative influence on the production of researchers, we have drawn up two samples. The first one is composed of the 37 university researchers[4] who publish the most frequently with other sectors. In 1995, these researchers produced 43.0% of their publications in collaboration with non-university partners, thus twice the national average. Their share was 25.9% in 1980. The average number of publications per researcher was 3.7 articles in 1980 compared to 7.1 in 1995. International collaboration also grew from 13.6% of publications in 1980 to 30.0% in 1995, in step, therefore, with the national trend.

The second sample is composed of the 100 most productive Canadian researchers. In this sample, interestingly, nearly half of the researchers (49) collaborate with industry. In 1995, 4.7% of their publications involved an industrial partner (as compared to fewer than 1% in 1980). Moreover, this sub-group publishes more than those researchers who do not collaborate. In 1995, they produced 682 papers, compared to 593 for the latter group. Over the period 1980-1995, their production increased 101.2% while the rate of growth for those who do not collaborate was 81.3%. Finally, the rate of international collaboration is

Table 3: University Publications Written in International Collaboration

Year	Number	%
1980	1,895	16.0%
1985	2,893	19.0%
1990	4,447	24.5%
1995	6,390	30.4%

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Table 4: Degree of Application of University Research (1995)

National publications*	**3.0**
with non-university partners	2.7
without non-university partners	3.1
International publications**	**3.2**
with non-university partners	2.8
without non-university partners	3.3

* Publications including only Canadian authors

** Publications including at least one foreign author

32.1% for those who collaborate with industry, compared to 37.6% for those who do not have such collaboration.

These data suggest that 1) the most productive scientists are also those who tend to form partnerships with other sectors; and 2) this tendency only slightly affects their level of international collaboration.

The impact of collaboration on university research

Among the criticisms often raised against collaboration of university researchers with industry and government laboratories is that such partnerships tends to favour more applied research and that it has less scientific impact.

In order to test these assumptions, we have used the classification scheme for determining the degree of application of science journals constructed by CHI Inc., which produces statistics for the National Science Foundation. Journals are classified by experts according to the degree to which they contain applied or basic research results. The scale runs from 1 (very applied) to 4 (very fundamental).

Table 4 clearly shows that research involving intersectoral collaboration is more applied than research undertaken solely among university researchers, and this conclusion applies to all disciplines. One should also note that the average level of application is not significantly different for national and international publications. Though this should not come as a surprise, these data thus confirm the hypothesis that university work done in inter-sectoral collaboration tends to be more applied.

To test the statement concerning the impact of inter-sectoral publications, we used the journal impact factor calculated by the Institute for Scientific Information. The impact factor is defined as the average number of citations received in a given year (in this case 1995) by articles published by a specific journal during the preceding two years. Every article is assigned the impact factor of the journal in which it is published. Table 5 shows that, contrary to expectations, the average impact of inter-sectoral collaborative research is not significantly different from that of university research. This means that papers originating from a collaboration between a university

Table 5: Average Impact Factor of University Research (1995)

National publications*	**2.2**
with non-university partners	2.3
without non-university partners	2.1
International publications**	**2.8**
with non-university partners	3.6
without non-university partners	2.6

* Publications including only Canadian authors

** Publications including at least one foreign author

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researchers and collegues from other sectors do not end up in less visible journals than a paper done only by university researchers. Moreover, inter-sectoral collaborative research involving foreign partners has a significantly greater impact (3.6) than all forms of national publications (2.2) and that which is conducted with foreign academic colleagues (2.6).

What is the impact of university-industry collaboration? The average impact factor is much lower than strictly university papers: 1.4 versus 2.4. But this is due mainly to the fact that more than a third of the papers (in 1995) came from a discipline with a small impact factor, that is engineering. If we look specifically at the impact factor of engineering papers written in collaboration with industry, it is almost equal to university papers in that field (0.6 compared to 0.7 respectively).

Conclusion

Comments concerning the effect of collaboration on university research are mostly inspired by current trends in R&D financing. R&D funding has, in fact, become more diversified: the relative share of industrial funding has increased steadily, at the expense of public funding, which has declined from 40.9% to 34.5% between 1986 and 1995 in OECD countries. An increase in the number of university researchers involved in inter-sectoral collaboration has also been observed: it is estimated that two-thirds of the most active researchers are currently engaged in such collaborative work (Godin, 1998).

Still, up to the present, this phenomena does not seem to have had any major deleterious effects on the scientific output (number of papers) and impact of Canadian researchers. For instance, the scientific production of universities rose 77.5% between 1980 and 1995[5]. At the heart of this activity, collaboration with partners increased by 155.2%, representing 21% of current publications, while collaboration with foreign countries jumped by 237.2%, representing 30.4% of current publications.

All of these data suggest that university research done in collaboration with industry, hospitals or government laboratories is not incompatible with quality. More generally, recent work has shown that no hard-and-fast dichotomy exists between researchers who conduct strictly applied or collaborative research (or re-orient their activities toward this type of research), and others who conduct only basic research. As could be expected, it is generally the same researchers who engage in both types of research activity. Secondly, researchers take part in collaborative research because of the advantages they can get, such as access to new areas of research, instruments, unpublished data or additional sources of funding (Meyer-Kramer and Schmoch, 1998: 841-842; Bataini, Martineau, and Trépanier, 1997).

In summary, the belief that collaborative research is detrimental to academic research does not seem grounded. One must, of course, continue to monitor the situation to see if it will change in the future.

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Endnotes

1 This section uses data for 1996 (the last complete year available), rather than those for 1995 as in the other sections, so as to render a more up-to-date picture of scientific production.

2 The figures are not mutually exclusive, the same publication may include the presence of more than one sector.

3 If we include the hospital sector in the university sector (given the fact that the majority of hospitals are university hospitals), the figures vary little. Collaborative production goes from 11.8% in 1980 to 18.1% in 1995 rather than from 14.6% to 21%.

4 The initial sample included 50 researchers. Upon verification, 13 of them proved not to be university researchers.

5 During the same period, publications in the world as a whole grew by 44.2%. Fluctuations and downswings match those observed in Canada: 13.7% (1980-84), 5.6% (1984-1988), 10.8% (1988-1992), 8.2% (1992-1995).